Modifying WWTPs to Achieve Nitrogen Removal

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Wave Four Energy Management Workshop

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Organisms and Their Means of Respiration

- Aerobic - use elemental oxygen
- Anoxic - use nitrate (NO_3) or nitrite (NO_2)
- Anaerobic - use other terminal electron acceptors (SO_4 , CO_2) or none at all
- Facultative - two or more means of respiration
- Fermentative - no terminal electron acceptor

CBOD Removal

- Heterotrophic
- Aerobic, anoxic, anaerobic
- Floc formers

Nitrification

- Autotrophic
- Aerobic
- Not floc formers

Denitrification

- Heterotrophic
- Anoxic (facultative)

Denitrification Reactions

For one gram of NO_3-N that is denitrified:

2.47 g of methanol (~3.7 g of COD) are consumed

0.45 g of new cells are produced

3.57 g of alkalinity are formed

Denitrification: Biochemical Reactions

Sewage as carbon source:

$$C_{10}H_{19}O_3N + 10NO_3^- \rightarrow 5N_2 + 10CO_2 + 3H_2O + 10\ OH^- + NH_3$$

Factors Affecting Denitrification

- **Substrate degradability**
- pH
- **Dissolved oxygen**
- Temperature

Impact of DO on Denitrification Rates

DO Conc, mg/L	Denitrification Rate
0.0	100%
0.1	40%
0.2	20%
0.3	10%

Oxygen Savings with Denitrification

For every gram of NO_3-N that is reduced to nitrogen gas, 2.86 grams of oxygen are saved.

Performance of Single-Sludge Denitrification

- Can achieve high N removals (85% to 95%)
- Does not necessarily enhance sludge settleability in final clarifier
- Uses carbon source in influent
- Reduces the energy requirements for BOD removal from the wastewater (2.86 lb O_2 equivalent per lb of NO_3-N removed)
- About one-half of alkalinity required for nitrification is produced in anoxic zone

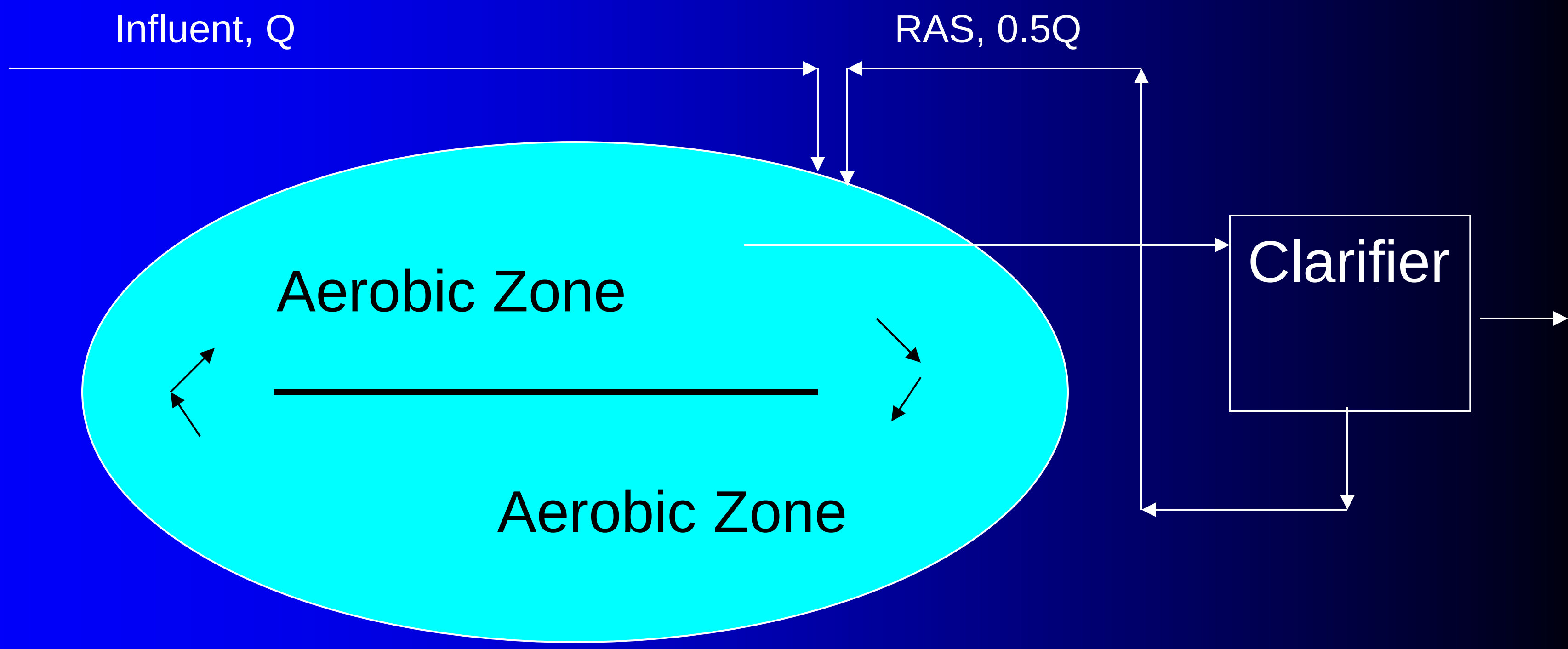
WWTP Changes to Achieve Nitrification-Denitrification

- Modify rectangular aeration basin with baffles to provide anoxic and aerobic zones
- Modify oxidation ditch to provide anoxic and aerobic zones
- Modify oxidation ditch operation with on/off aeration cycles to achieve denitrification
- Modify SBR system to include anoxic and aerobic cycles
- Modify step-feed system to include alternating anoxic and aerobic zones

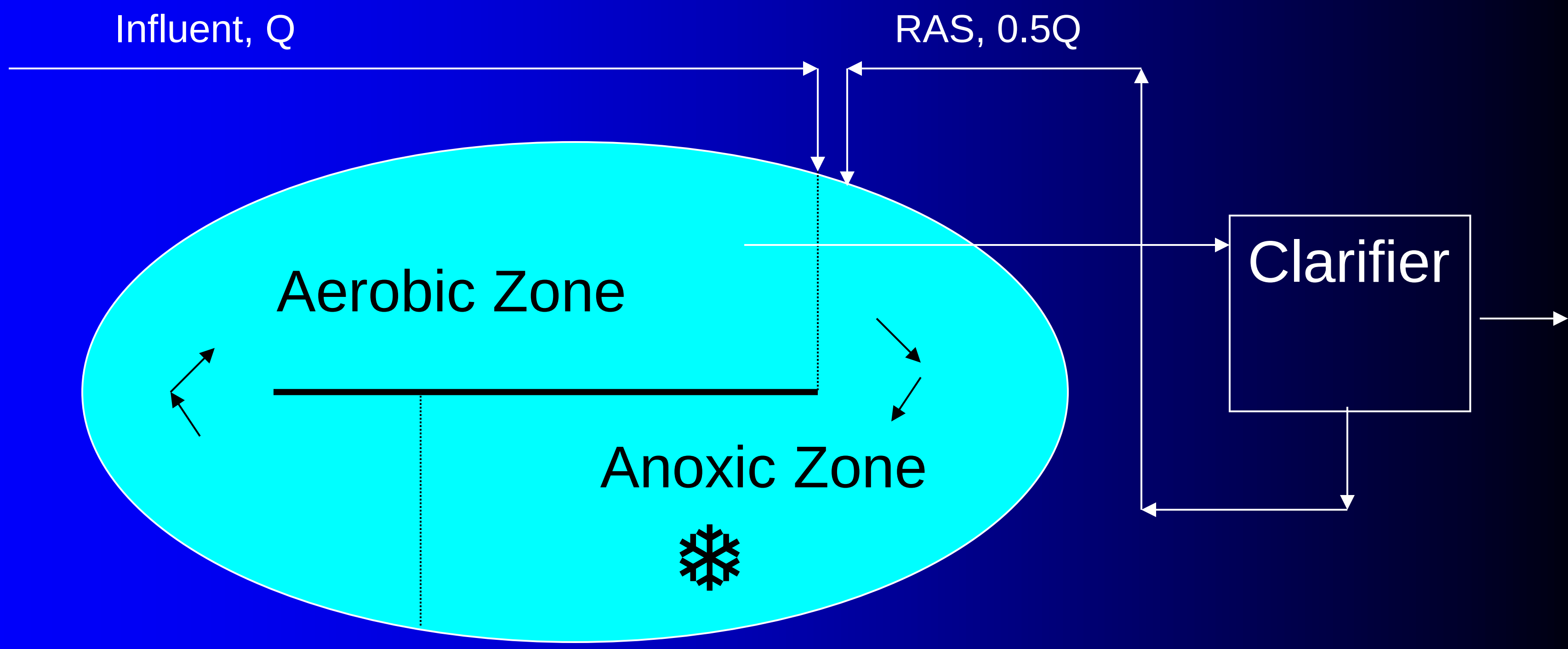
Rectangular Aeration Basin

Modified Rectangular Aeration Basin

Oxidation Ditch Before Modification



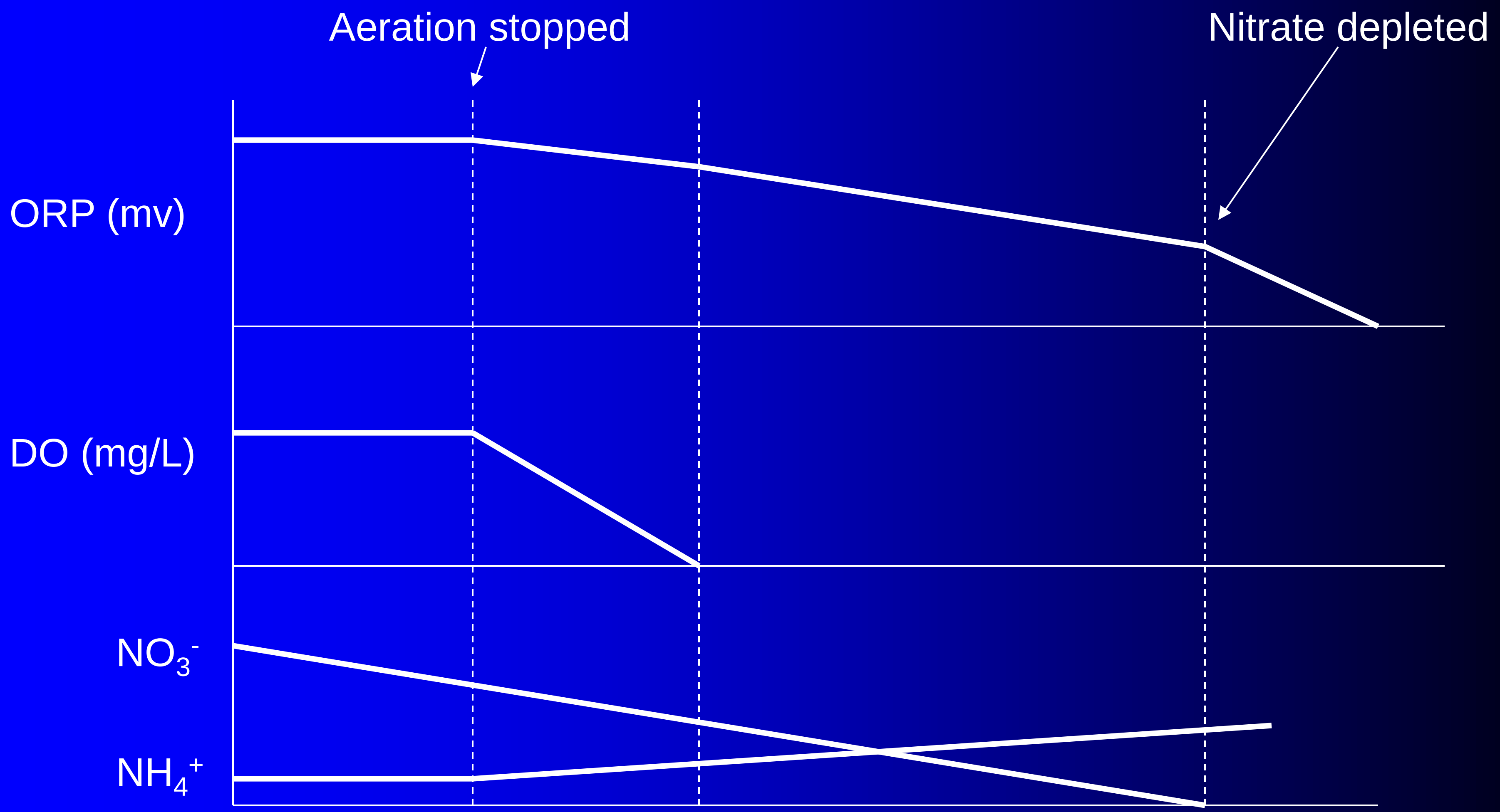
Oxidation Ditch After Modification



Intermittent Aeration for N Removal in Oxidation Ditch

- Cycle time for on/off operation of aerators may vary
- Process control with DO and ORP monitoring
- When aerator is off, must provide mixing
- During off period, oxidation ditch becomes anoxic reactor, and nitrate is consumed as bacteria degrade BOD
- ORP data are used to terminate off cycle and start aeration

Change in ORP and DO in On/Off Operation



Factors Affecting On/Off Operation

- Oxidation ditch HRT
- Influent flow rate
- TKN and BOD concentrations
- Number of on/off cycles per day
- Ditch MLSS concentration

Nitrogen Removal in Oxidation Ditch Using DO Control

Expected Effluent Quality:

BOD_5	5 - 15 mg/L
TSS	10 - 20 mg/L
Ammonia-N	< 1 mg/L
NO_x-N	5 - 10 mg/L
Total N	7 - 14 mg/L

Actual N Removal in Oxidation Ditches

WWTP	TKN	NH_3-N	NO_3-N	N rem %
A	3.1	1.4	19.3	2
B	1.6	0.9	2.3	86
C	2.5	1.1	9.7	51
D	3.9	1.9	8.3	80
E	3.3	0.5	12.4	72

Nitrogen Removal in SBRs

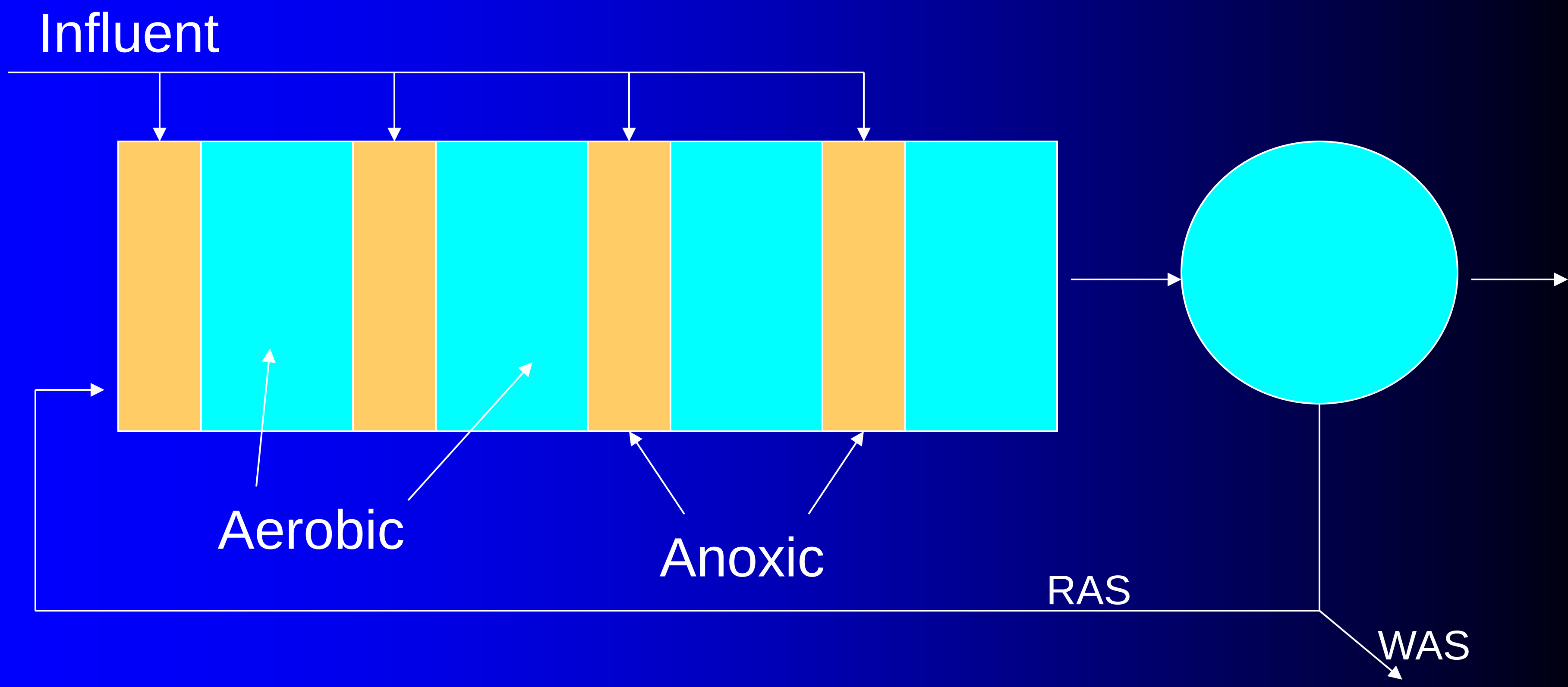
- Use anoxic and aerobic cycles to effectively remove nitrogen
- Cycles are:
    - Fill (anoxic)
    - React (aerobic/anoxic)
    - Settle
    - Decant

Nitrogen Removal in SBRs

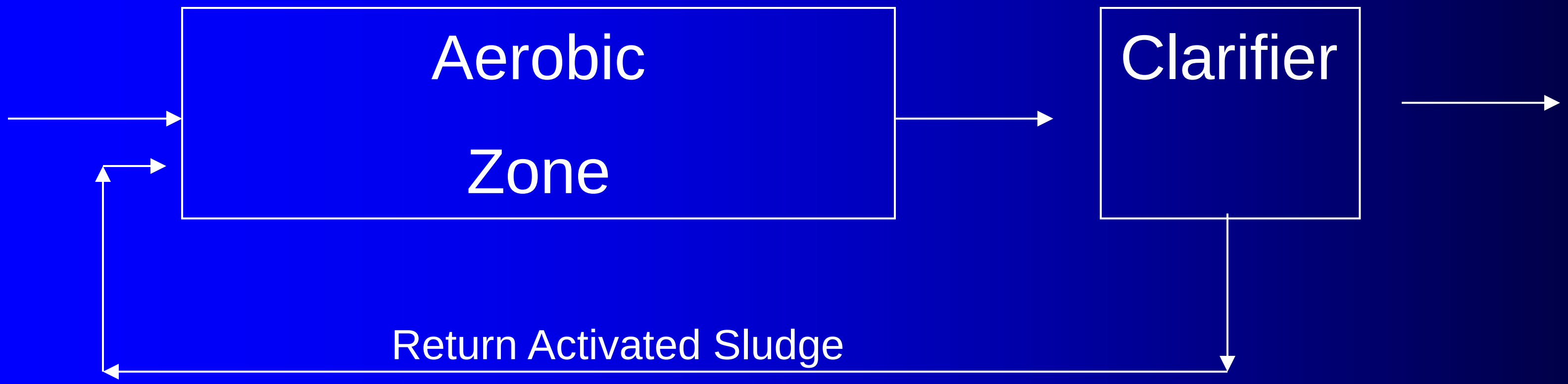
Expected Effluent Quality:

BOD_5	5 - 15 mg/L
TSS	10 - 20 mg/L
Ammonia-N	< 1 mg/L
NO_x-N	3 - 10 mg/L
Total N	5 - 12 mg/L

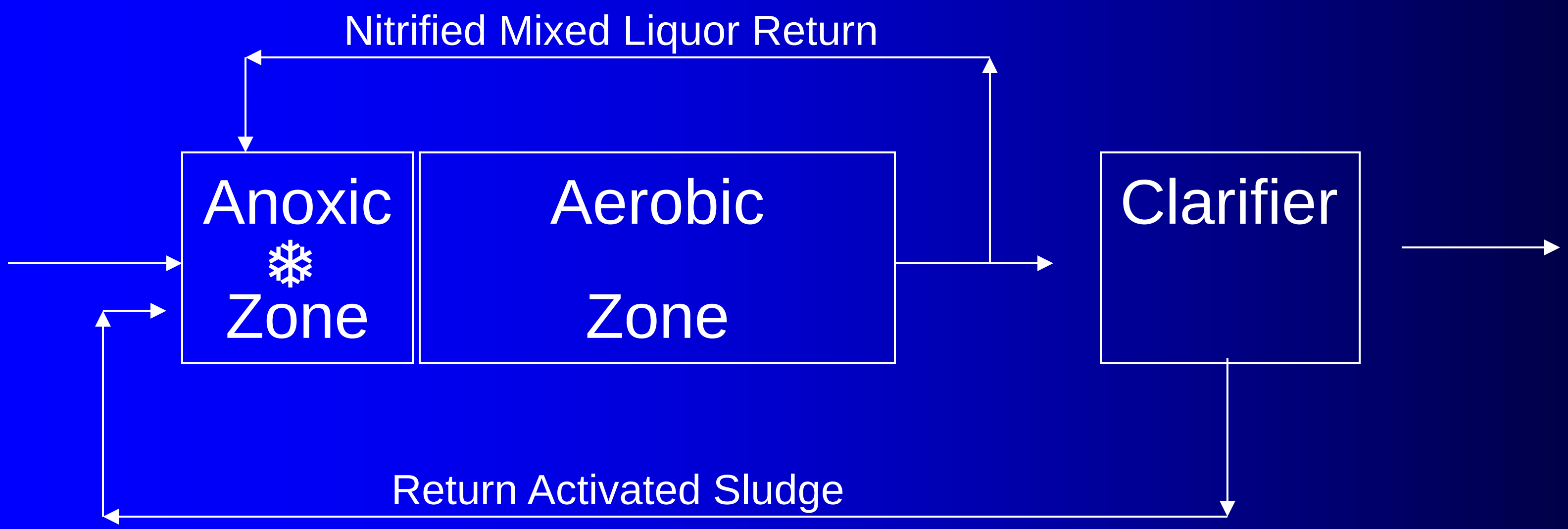
N Removal in Step-Feed Process



Conventional Activated Sludge



Add an Anoxic Zone using Baffle, Mixed Liquor Return, and Mixing



Before and After Effluent Quality

	Before	After
BOD_5	5 - 25 mg/L	5 - 15 mg/L
TSS	10 - 25 mg/L	10 - 20 mg/L
Ammonia-N	1 - 5 mg/L	1 - 2 mg/L
NO_x-N	8 - 15 mg/L	3 - 9 mg/L
Total N	10 - 20 mg/L	5 - 12 mg/L
*SVI	125 - 225	50 – 125

* impacts on mixed liquor at one facility

Principles in Implementing N Removal

- Consider a wide variety of alternatives
  - use on/off operation of aeration units
  - add anoxic zone and mixed liquor recirculat’n
  - optimize anoxic/aerobic periods
  - adjust SRT to enhance nitrogen removal
- Invest in plant-specific waste characterization data
- Engineer and operators should discuss changes
- Tailor to specific plant situation
- Balance risk and cost

Case Study: Pell City, AL WWTP

Single Oxidation Ditch

Design flow rate (ave daily) = 4.75 mgd

Actual flow rate (ave daily) = 2.2 mgd

Influent BOD_5 concentration = 170 mg/L

Influent TSS concentration = 260 mg/L

Influent TKN concentration = 30 mg/L

Volume of the ditch = 2.0 mil gal

Pell City, AL WWTP

Pell City, AL WWTP

Previous Operating Conditions at Pell City, AL WWTP

Actual aeration basin detention time = 22 hrs

F/M ratio = 0.045 lb BOD_5/(day-lb MLVSS)

VOLR = 11.7 lb BOD_5/(day-thou cu ft)

Solids Retention Time (SRT) = 50 days

MLSS concentration = 5,800 mg/L

MLVSS concentration = 4,100 mg/L

TSS sludge production = 1,770 lb/day

Oxygen requirements = 6,200 lb/day

Previous Operating Conditions at Pell City, AL WWTP

Oxygen supplied = 6,000 lb/day (three 50-hp rotors running 24/7)

Effluent $CBOD_5$ conc = 4 mg/L

Effluent TSS conc = 8 mg/L

Effluent amm-N conc = 0.2 mg/L

Effluent TKN conc = 1 mg/L

Effluent Total P conc = 0.7 mg/L (w/ alum)

Effluent NO_x conc = 15 mg/L

Effluent Total N conc = 16 mg/L

Denitrification at Pell City, AL WWTP

Turn three 50-hp rotors off 5 hours per day

Estimated energy savings = 14,400 kWh/mo

Estimated cost savings = $1,700/mo (12%)

Current effluent NO_x conc = 10 mg/L

Current effluent Total N conc = 11 mg/L

Reduction in effluent Total N = 92 lb/day

= 17 tons/year